

BELLCOMM. INC.

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SUBJECT: The Aerodynamic Gravity Substitute
Workbench for Skylab - Case 620

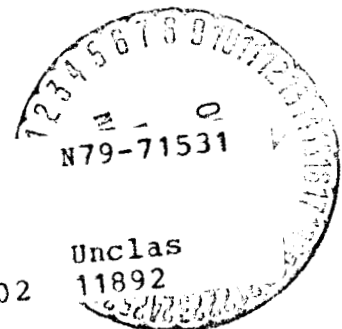
DATE: September 25, 1970

FROM: M. Liwshitz
T. T. J. Yeh

ABSTRACT

An examination of the proposed Aerodynamic Gravity Substitute Workbench shows the present configuration results in low effective forces. Computation of the drag force exercised by the workbench on metallic objects representative of parts and tools encountered in work situations, reveals that this force amounts to 1% or less of the force of gravity acting on similar bodies at the surface of the earth. Only a flat disk-shaped body would experience a sizable acceleration, on the order of 0.2g, provided its flat surface always remains oriented normal to the air stream, an unlikely situation for a small object in accidental motion over the workbench. The requirements for the use of the Aerodynamic Gravity Substitute Workbench should be examined in the light of the characteristically low force levels determined in this study.

(NASA-CR-113625) THE AERODYNAMIC GRAVITY
SUBSTITUTE WORKBENCH FOR SKYLAB (Bellcomm,
Inc.) 7 p



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MEMORANDUM FOR FILE

I. The Proposed Experiment

In order to explore the potential of aerodynamic forces as an alternative gravity substitute in a shirt-sleeve work environment where loose objects have to be handled, an aerodynamic workbench experiment, M507, has been proposed for Skylab A. Its hardware consists of a porous plate such as a stainless steel screen, which is the work area, and a fan located below it that draws the air through the perforations. This then generates a steady air stream directed towards the working surface, producing a force that in effect drags or "sucks" loose objects to the surface and holds them there. The air is finally returned to the system through a diffuser.

Representative experiment parameters are as follows:

Air stream velocity	1-5 m/sec
Ambient pressure	5psi
Ambient temperature	70°F

In principle the experiment could be performed under different conditions, but the indicated values are as close to the anticipated actual conditions in Skylab as is necessary for a simple analysis of the proposed experiment. This analysis shows that the force levels attained in the proposed configuration are quite low, indicating a need to reexamine the potential uses of the workbench.

II. Numerical Comparison of the Drag Force with Terrestrial Surface Gravity, g...

The aerodynamic drag force D , experienced by a body exposed to a gas stream is given by

$$D = \frac{1}{2} C_D \rho v^2 A \quad (1)$$

where

D = the total drag force exerted on the body

C_D = dimensionless drag coefficient

ρ = air mass density

V = relative air stream velocity

A = effective area of the body.

For geometrically similar bodies C_D is a function of Reynolds number R only, and is usually determined in experiments. The Reynolds number is given by

$$R = \frac{\rho V d}{\mu}$$

where μ is the viscosity of the ambient gas and d is a characteristic length of the body. The variations of C_D over the wide range of possible values for R have only been established for simple geometries such as spheres, cylinders, "infinite" flat plates and airfoils. Figure 1 shows the dependence of C_D on R for spheres, cylinders, and disks^(1,2).

In the following we estimate the drag force on three typical bodies, with sizes and shapes that are representative of objects to be encountered in actual work situations such as small parts and tools. Table 1 summarizes the relevant physical parameters of these objects and the drag force D acting on them under the assumed conditions of the experiment. Likewise Table 1 shows the value of gravitational force $F=mg$ acting on these objects at the surface of the earth, and lists the ratio D/F . The assumed density of the material of these objects is 5gm/cm^3 .

TABLE 1
Comparison of Drag Force and Gravitational Force

Object	Dimensions	R^*	C_D	D(dynes)	F(dynes)	D/F
Sphere	d(diameter) =1cm	2.4×10^2 (V=1 m/sec)	.8 ⁽¹⁾	1.37	2.56×10^3	$\sim 5 \times 10^{-4}$
		1.2×10^3 (V=5 m/sec)	.45 ⁽¹⁾	19.3	"	$\sim 7 \times 10^{-3}$
Cylinder	d=1cm l(length) =5cm	2.4×10^2	1.4 ⁽¹⁾	14.0**	1.92×10^4	$\sim 7.3 \times 10^{-4}$
		1.2×10^3	1.0 ⁽¹⁾	2.5×10^2 *	"	$\sim 1.3 \times 10^{-2}$
Disc	d=1cm t(thickness) =1mm	2.4×10^2	1.6 ⁽²⁾	5.0***	3.85×10^2	$\sim 1.3 \times 10^{-2}$
		1.2×10^3	1.0 ⁽²⁾	78.4***	"	$\sim 2 \times 10^{-1}$

*In this and subsequent columns the upper entry in each category corresponds to an air stream velocity of 1m/sec, the lower entry corresponds to 5m/sec.

**motion of cylinder normal to cylinder axis

***motion in direction of disc axis

III. Conclusions

Table 1 shows that for the given values of physical parameters and conditions of operation the aerodynamic gravity substitute on the workbench amounts to $\sim 1\%$ or less of the gravitational force acting on the test objects at the surface of the earth. Only a light disk whose flat surface remains always exposed to normal impact of the air stream, experiences a force comparable to lunar surface gravity. Because this drag force depends so strongly on orientation, the actual force encountered by any small part in accidental motion, and therefore with no fixed orientation, will be reduced to the levels typical for the other bodies in Table 1. Only if deliberately placed on the surface of the workbench in the proper orientation, will even a flat object stick to the surface with appreciable force. Possibly the ratio D/F can be increased by a factor ~ 5 if one considers objects composed of lighter materials, but few materials used in technical practice are substantially less dense than water.

It has been argued that such low levels of force or acceleration may be sufficient in a zero-g environment to fulfill both functions of gravity, namely to assure that an object released over the bench lands on the surface of the bench, and that an object already residing on the surface is held there. If any of the indicated metallic objects has a sizeable component of velocity, say ≥ 20 cm/sec, transverse to the air stream, it is not likely to land in its flight on the surface of the bench. On the assumption of .01 g drag acceleration the body traverses in ~ 4.5 seconds a distance of ~ 1 meter and reaches at the end of this period a velocity of only ~ 45 cm/sec. Under such conditions, potential problems exist indicating that one should restudy the requirements for the Workbench. The case for the "sticking" force of the perforated surface for objects already residing on it appears stronger, but in view of the above problem, one might consider the use of adhesive surfaces.

In principle the drag can be increased by increasing the air stream velocity. However, an air stream velocity of 5m/sec appears to be the present design limit for the workbench⁽³⁾. Also, as Table 1 illustrates, the increase in velocity is less effective than may be surmised from Equation (1). For example, increasing the velocity by a factor of 5 does not result in a 25 fold increase in drag force, because the increase of R proportional to velocity reduces C_D .

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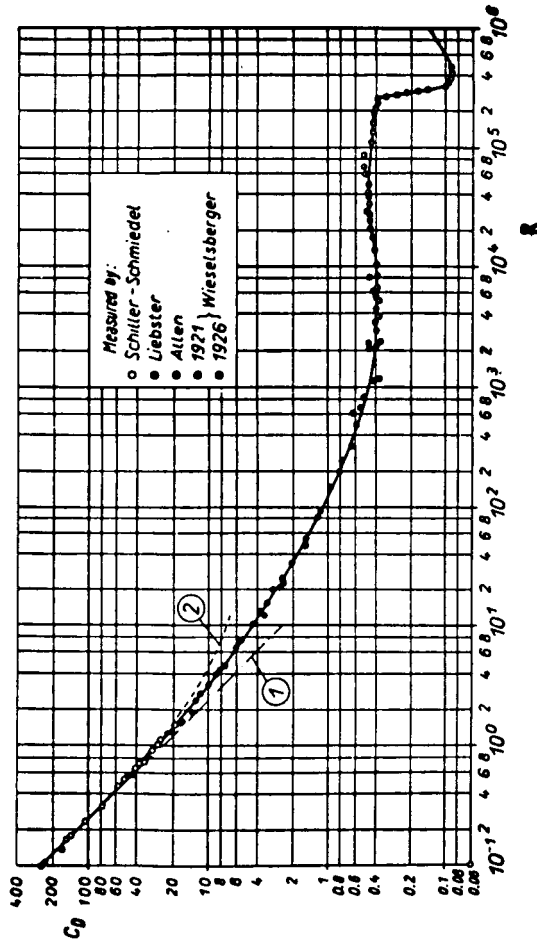
T. T. J. Yeh

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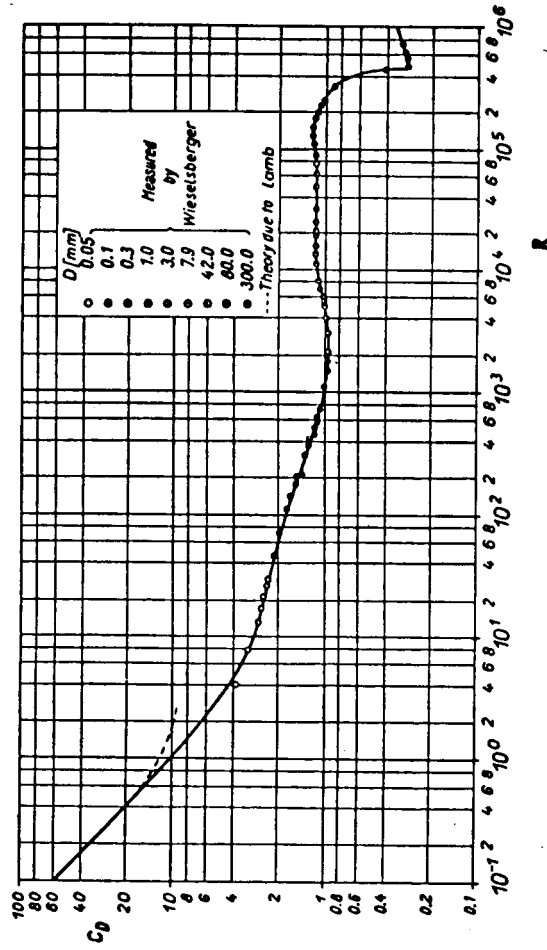
Attachment
References
Figure 1

REFERENCES

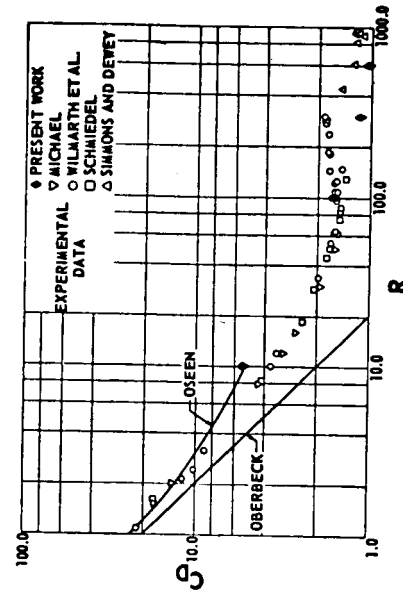
1. Schlichting, H., Boundary Layer Theory, McGraw-Hill, 1960.
2. Rimon, Y., Phys. Fluids Suppl. II, II-65, 1969.
3. Anderson, G. M., Personal Communication.



(a)



(b)



(c)

FIGURE 1 - DRAG COEFFICIENT C_D VERSUS REYNOLDS NUMBER R .
 (a) SPHERES, AFTER REF. 1, (b) CYLINDERS, AFTER REF. 1,
 (c) DISKS, AFTER REF. 2.

BELLCOMM, INC.

SUBJECT: The Aerodynamic Gravity Substitute FROM: M. Liwshitz
Workbench for Skylab - Case 620 T. T. J. Yeh

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